Gluon polarization (ΔG) at PHENIX

SWADHIN TANEJA
(SUNY STONY BROOK)
FOR THE PHENIX COLLABORATION

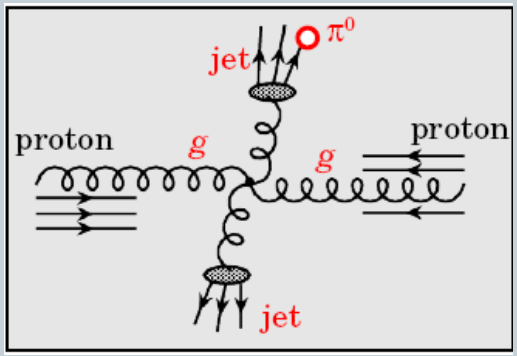
Outline

- Introduction
- RHIC performance and PHENIX experiment
- PHENIX cross section & double longitudinal asymmetry (A_{LL}) measurements
- Extracting ΔG from A_{LL}
  - Resulting constraint on ΔG
- Experimental and theory uncertainties on ΔG
- Summary and Outlook

Introduction

- Proton spin structure, $\frac{1}{2}_{proton} = \frac{1}{2}\sum_q \Delta q + \Delta G + L_q + L_g$
  - Proton spin puzzle (1988 EMC expriment)
  - Global analysis, $\Delta q \sim 25\%, Q^2 = 10\ GeV^2$ [PRL101:072001,2008]
  - ΔG not well constrained by fits to pDIS , $g_1(x, Q^2)$, at this time
- Polarized p+p collisions for ΔG measurement
  - π^0, jet , direct photons etc.
  - double helicity asymmetry (A_{LL})

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$



- Inclusive π^0 at mid-rapidity ($|\eta| < 0.35$) is PHENIX main channel for the determination of ΔG at this time.

Extracting ΔG from A_{LL} measurements

- Theory interpretation of A_{LL} $\pi^{0,+/-}$,

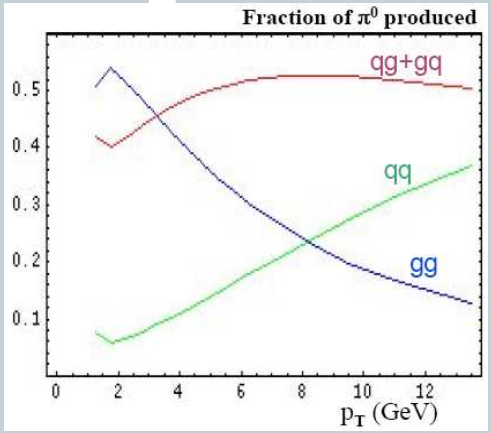
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma} \otimes D_{\pi/c}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma} \otimes D_{\pi/c}}$$

  - pol. (Δf) and unpol. pdf's (f) from DIS (mainly)
  - pol. (Δσ) and unpol. (σ) hard scattering cross section from NLO PQCD
  - fragmentation functions ($D_{\pi/c}$), from e^+ e^- , Semi Inclusive DIS and pp

- Three processes contribute to A_{LL} $\pi^{0,+/-}$,

$$A_{LL} \simeq a_{gg}\Delta g^2 + b_{gq}\Delta g\Delta q + c_{qq}\Delta q\Delta q$$

  - Need to make sure pQCD, factorization, universality in pdf and fragmentation WORK



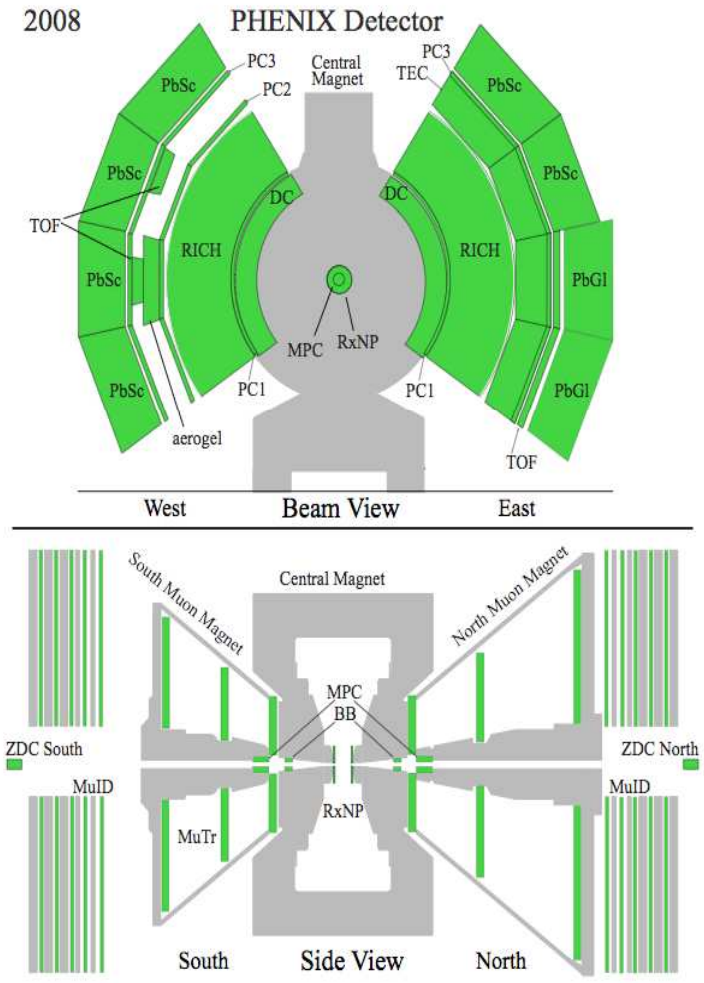
RHIC Heavy Ion Collider (RHIC)

- Data accumulation in longitudinally polarized p+p Runs
- 05'+06' ~ 200 times increase in FOM than 03'+04'
- 09' run at $\sqrt{s}$ = 500 GeV , L^{*} ~ 9 pb^{-1} , P ~ 40%
- low $\sqrt{s}$ run for better sensitivity to large x ($x \sim 1/\sqrt{s}$).

Longitudinal

Year	$\sqrt{s}$ [GeV]	L [pb^{-1}] (recorded)	Pol. [%]	FOM (P^4L)
2003	200	0.35	27	0.0019
2004	200	0.12	40	0.0031
2005	200	3.4	49	0.20
2006	200	7.5	57	0.79
2006	62.4	0.08	48	0.0042
2009	200	14	57	1.2

PHENIX Detector



π^0, η, γ detection

- Electromagnetic Calorimeter (PbSc/PbGl):
  - High p_T photon trigger to collect π^0's, η's, γ's
  - Acceptance: $|\eta|<0.35$, $\varphi = 2 \times \pi/2$
  - High granularity ($\sim 10*10 mrad^2$)

π^+/ π^-

- Drift Chamber (DC) for Charged Tracks
- Ring Imaging Cherenkov Detector (RICH)
  - High p_T charged pions ($p_T>4.7$ GeV).

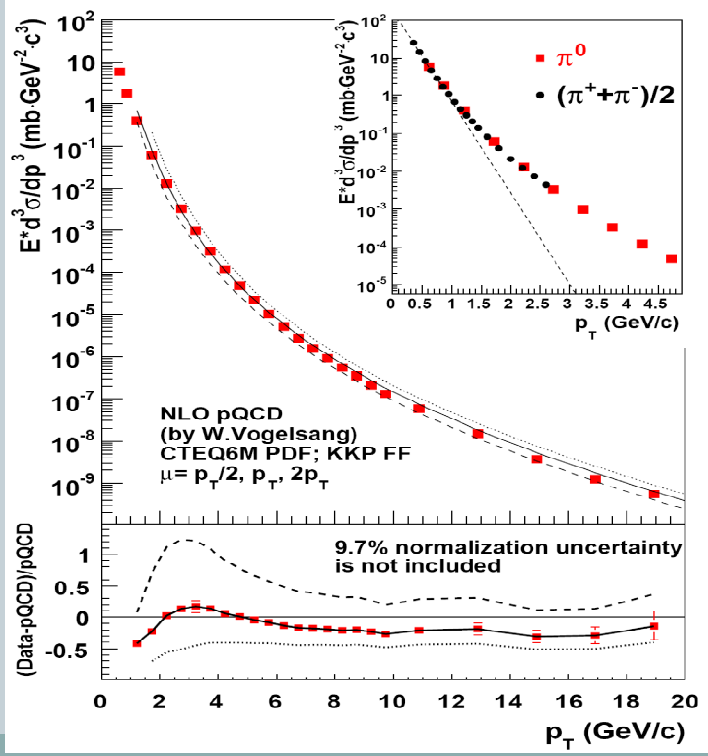
Luminosity (Global) Detectors

- Beam Beam Counter (BBC)
  - Acceptance: $3.0< \eta <3.9$
- Zero Degree Calorimeter (ZDC)
  - Acceptance: ±2 mrad about beam axis

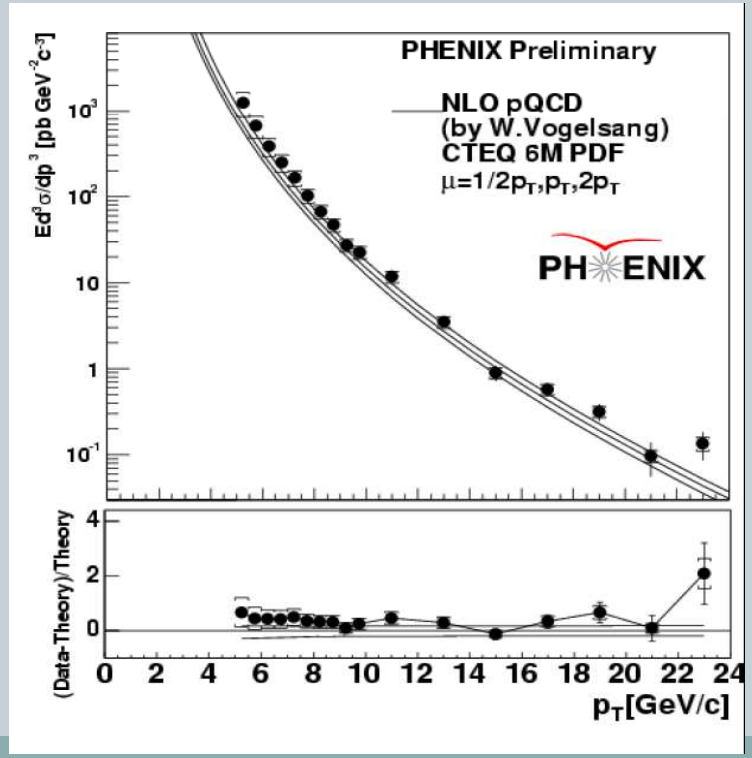
Cross section results from PHENIX

- π^0 , direct γ cross section
  - NLO PQCD shows agreement with the data

π^0 @ 200 GeV (PRD76, 051106)



Direct γ @ 200 GeV (PRL 98, 012002)



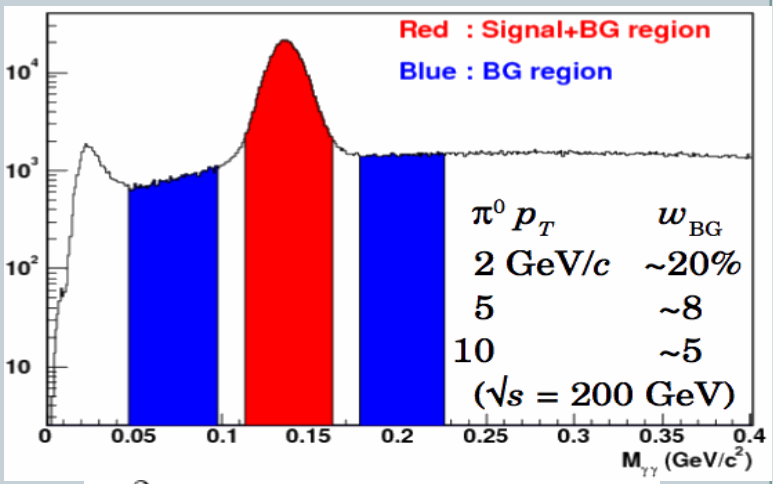
Measurement of π^0 A_{LL}

- Well developed method
  - 2003 (PRL 91, 241803)
- π^0 yield measurement
  - $\pi^0 \rightarrow \gamma\gamma$ BR ~ 98.8 %
  - Combinatorial BG fraction

    $w_{BG} = N_{BG} / (N_{BG} + N_{\pi})$
- A_{LL} measurement
  - signal A_{LL} is corrected for background A_{LL},

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, R = \frac{L_{++}}{L_{+-}}$$

  - P_B , P_Y (~55%) beam pol. , less than 10 % relative error in $P_B.P_Y$
  - R : relative luminosity, δ_{ALL} = 2 x 10^{-4} in 2005, 7 x 10^{-4} in 2006
  - N_{++} (N_{+-}) π^0 yield with same (opposite) helicity of colliding beams

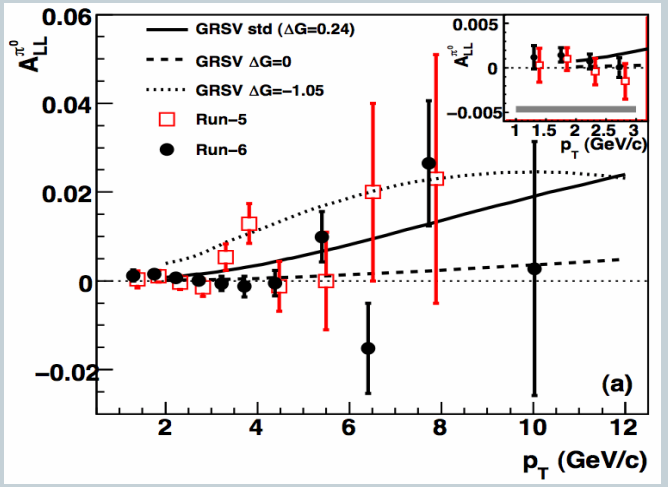


$$m^2_{\pi^0} = 2E_1E_2(1 - cos\theta)$$

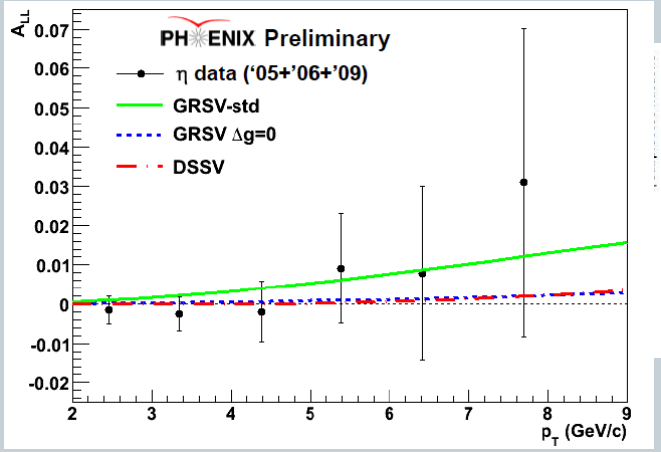
$$A_{LL}^{\pi^0} = \frac{A_{LL}^{\pi^0+BG} - w_{BG}A_{LL}^{BG}}{1 - w_{BG}}$$

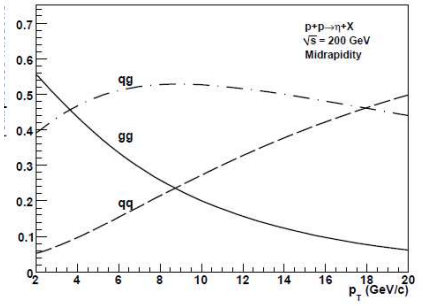
π^0 and η asymmetry results from PHENIX

- π^0 A_{LL} at 200 GeV,
  - High statistics measurement
  - 2005: PRD76, 051106
  - 2006: PRL 103, 012003 (2009)



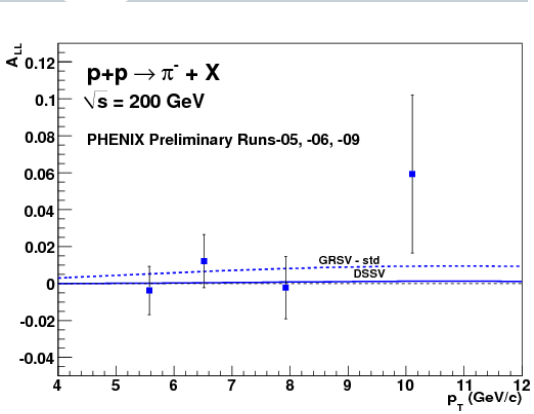
- η at 200 GeV
  - Analysis similar to π^0
  - Fractional sub process differ somewhat
  - Independent confirmation of ΔG

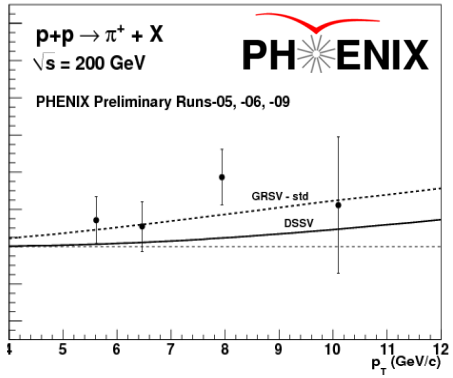




π^+, π^- and γ asymmetry results from PHENIX

- Charged pion at 200 GeV
  - Favored/Disfavored FF
    - different qg contributions for $\pi^{0,+,-}$
    - access sign of ΔG

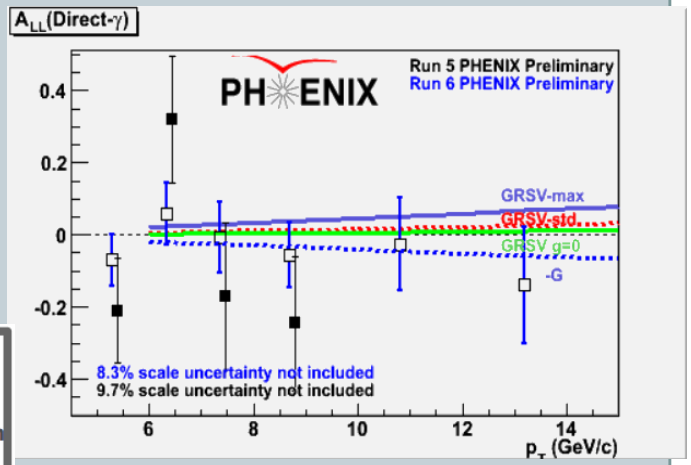


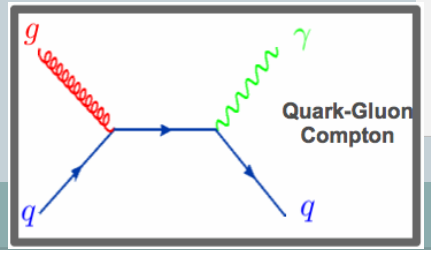


$$A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-} \Rightarrow \Delta G > 0$$

$$A_{LL}^{\pi^+} < A_{LL}^{\pi^0} < A_{LL}^{\pi^-} \Rightarrow \Delta G < 0$$

- Direct photon A_{LL} at 200 GeV
  - quark gluon scattering dominates
  - clean channel, isolation cut, linear in ΔG
  - higher statistics needed





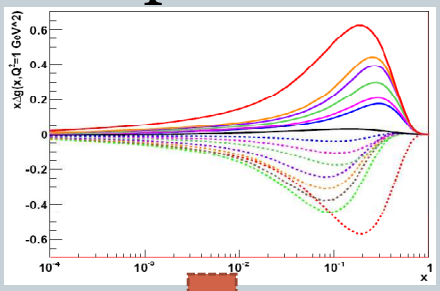
CONSTRAINING ΔG

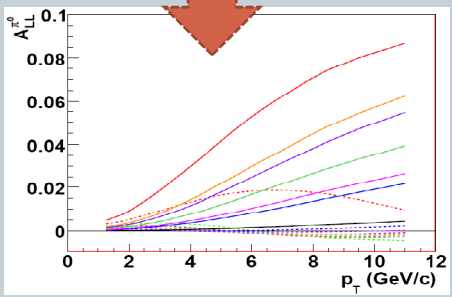
Constraining ΔG

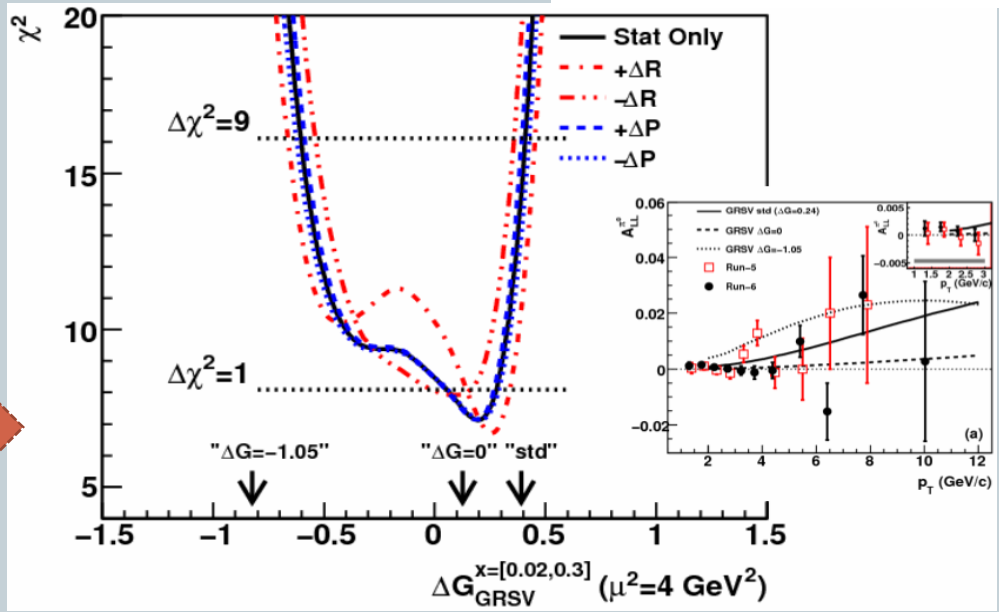
GRSV PRD63 (2001) 094005

- Vary ΔG in GRSV fit, generate A_{LL} , calculate χ^2 for each expectation curve, plot profile.

PRL 103, 012003 (2009)







- χ^2 profile is asymmetric so $\Delta\chi^2$ =1 and 9 (1σ and 3σ) are significant

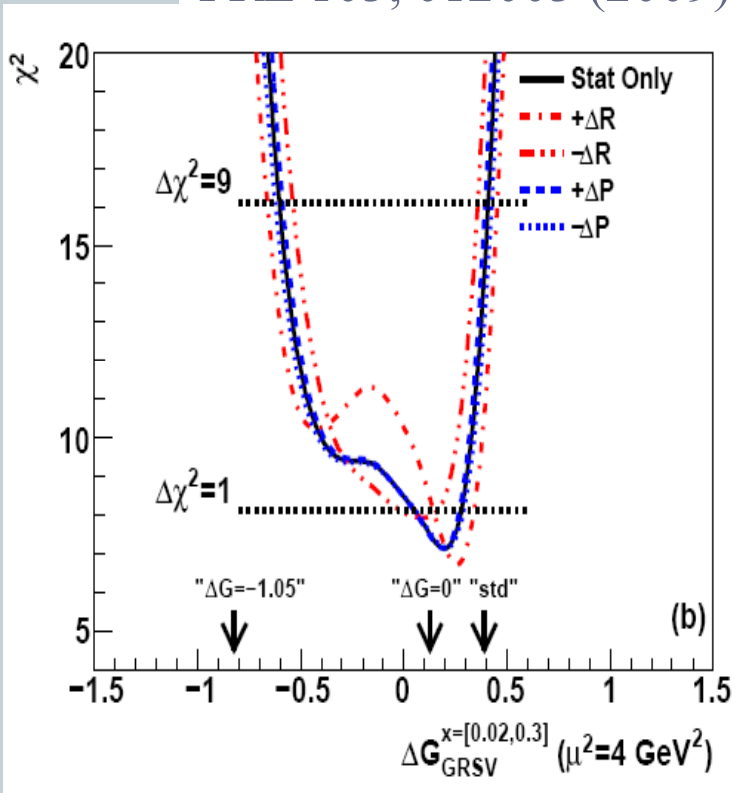
From just the statistical uncertainty :

$$\Delta G^{[0.02,0.3]}_{\mathrm{GRSV}} = 0.2 \pm 0.1\ (1\sigma)\ \text{and}\ 0.2^{+0.2}_{-0.8}\ (3\sigma)$$

Constraining ΔG : Systematic Uncertainties

- Systematic uncertainty
  - The two primary systematic uncertainties are from polarization (ΔP) and relative luminosity (ΔR).
  - The polarization uncertainty is insignificant when extracting ΔG.
  - Uncertainty in relative luminosity while small is significant when extracting ΔG.

PRL 103, 012003 (2009)



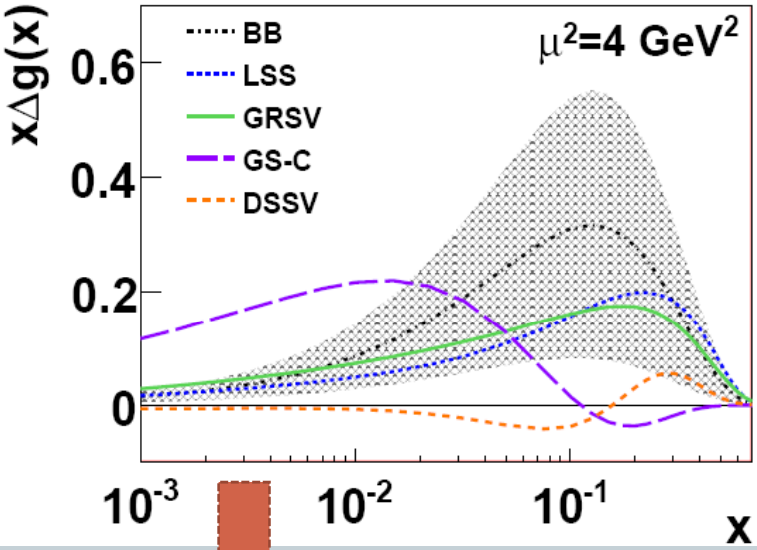
Systematic uncertainty gives an additional +/- 0.1

Constraining ΔG : Theory Uncertainties

- PDF functional form dependence as a function of x.
- Theory energy scales, μ (factorization, fragmentation and renormalization scale) dependence.
- Uncertainty in fragmentation functions (DSS, KKP).
- Strong coupling constant uncertainty dependence.

Theory Uncertainty: Parameterization

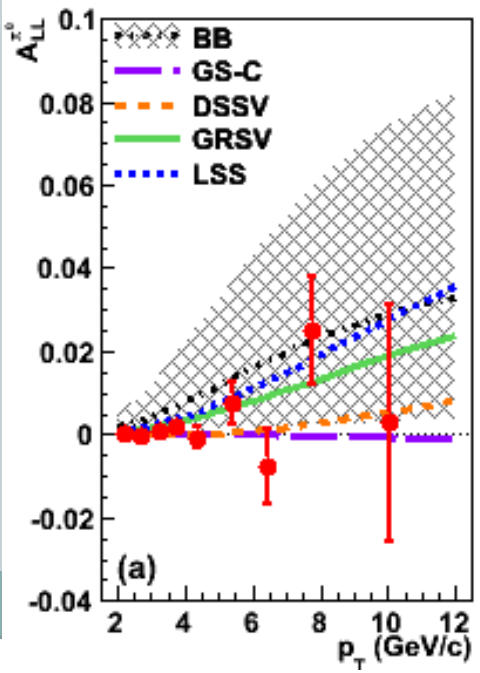
PRL 103, 012003 (2009)

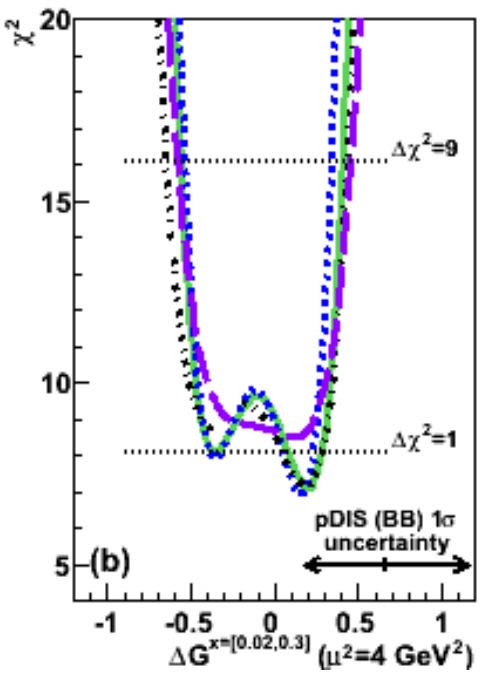


Group	Published best fit $\Delta G^{[0,1]}$	$\Delta G^{[0.02,0.3]}$
GS-C	0.95	0.18
DSSV	-0.05	-0.03
LSS	0.60	0.37
GRSV	0.67	0.38
BB	0.93	0.67

- The gluon polarization distribution as a function of x from five fits to polarized DIS data.

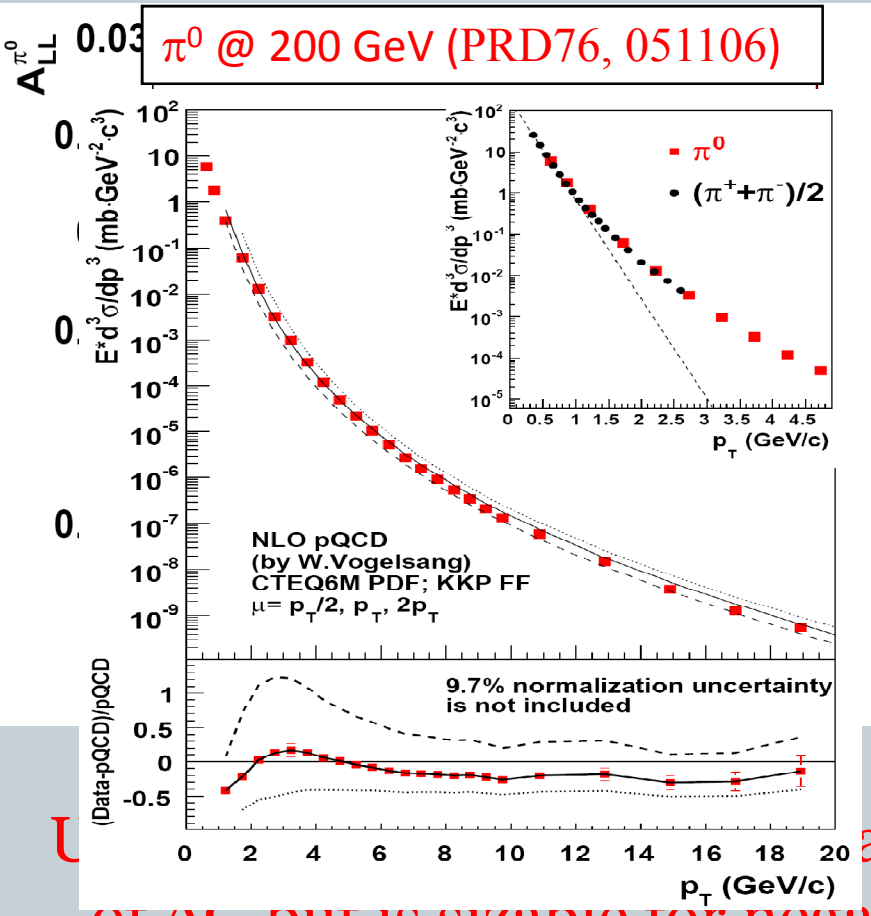
$$-0.7 < \Delta G^{[0.02,0.3]} < 0.5$$



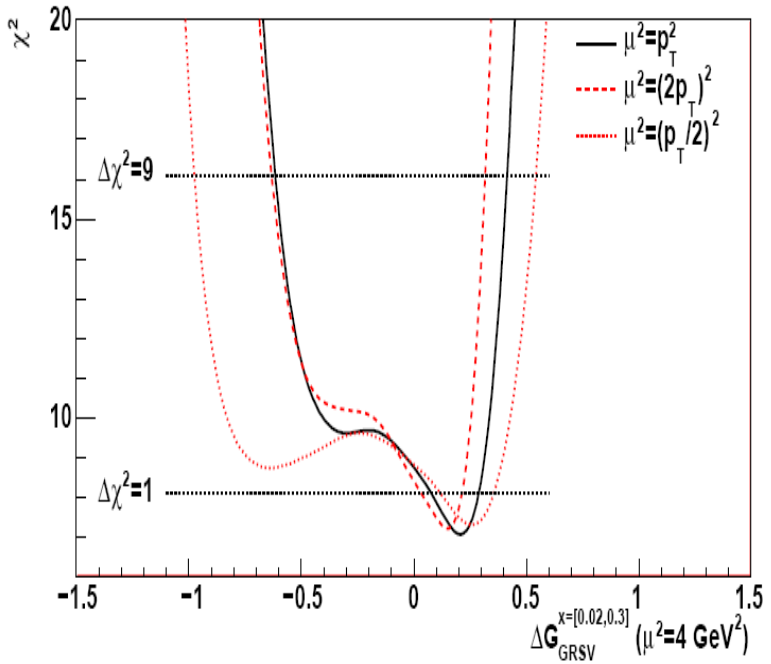


Theory Uncertainty: Energy Scale (μ)

π^0 @ 200 GeV (PRD76, 051106)



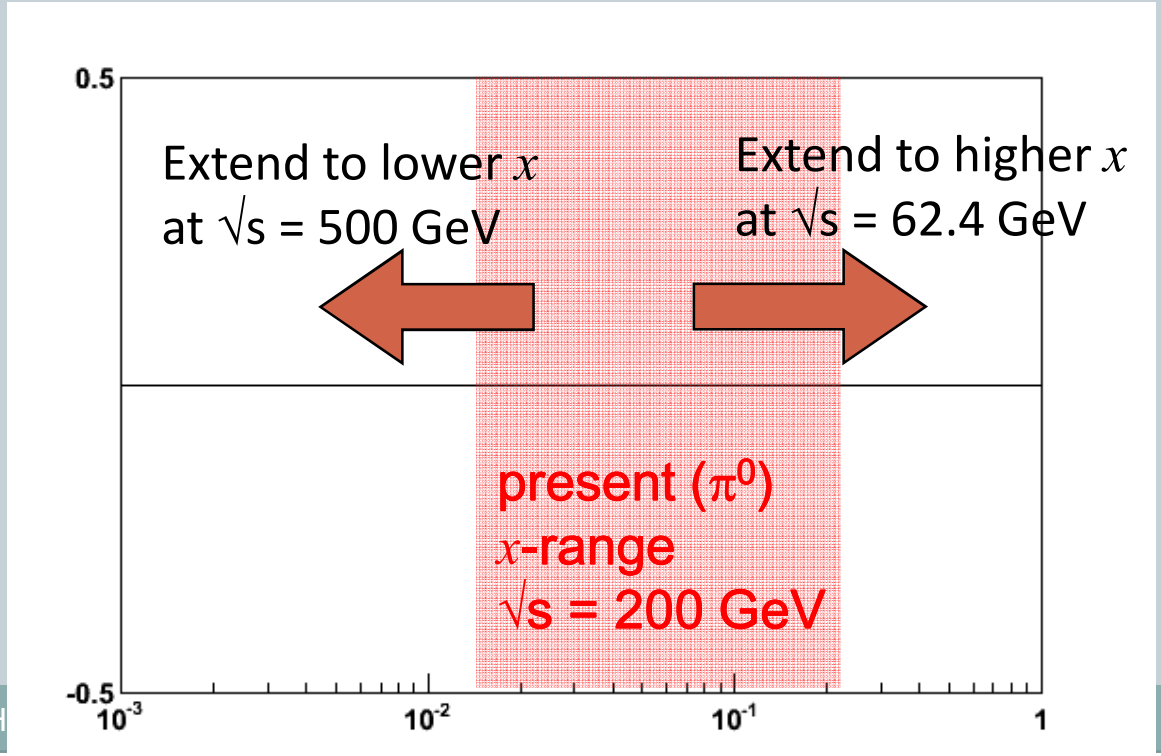
PRL 103, 012003 (2009)



Uncertainty is small (0.1) for the positive values of ΔG but is sizable for negative values.

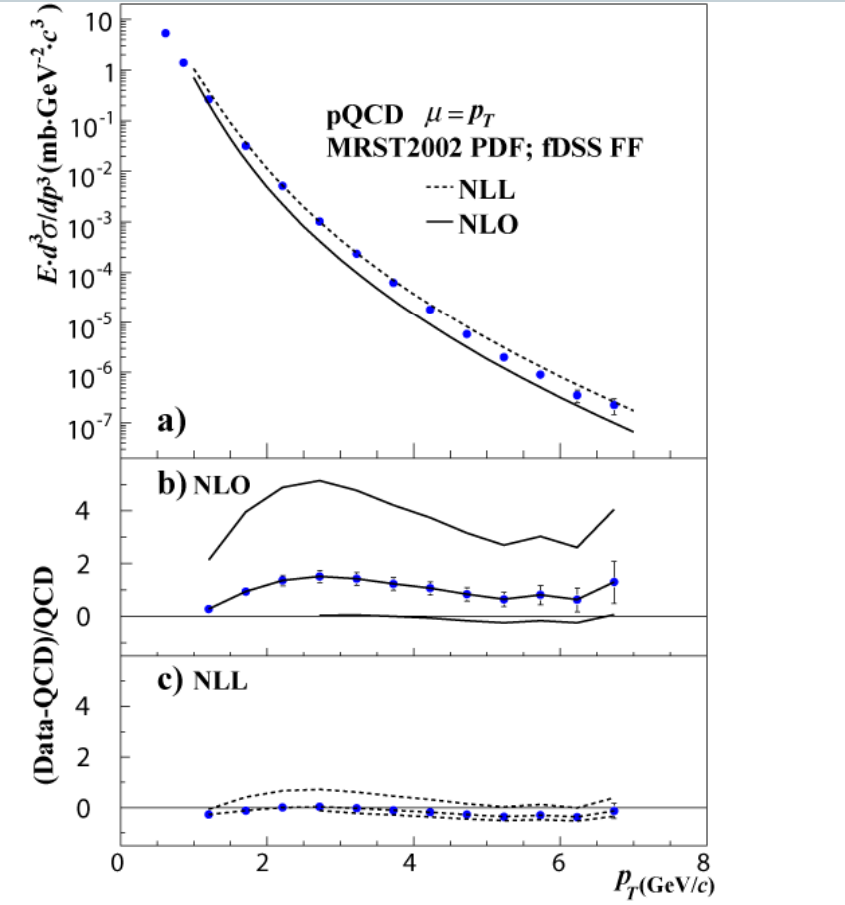
Theory Uncertainty: gluon x range

- To get a complete picture of ΔG, need as wide an *x* range as possible.
  - We can extend our *x* coverage towards lower *x* at √s = 500 GeV (Run9) and towards higher *x* at √s = 62.4 GeV (Run6)

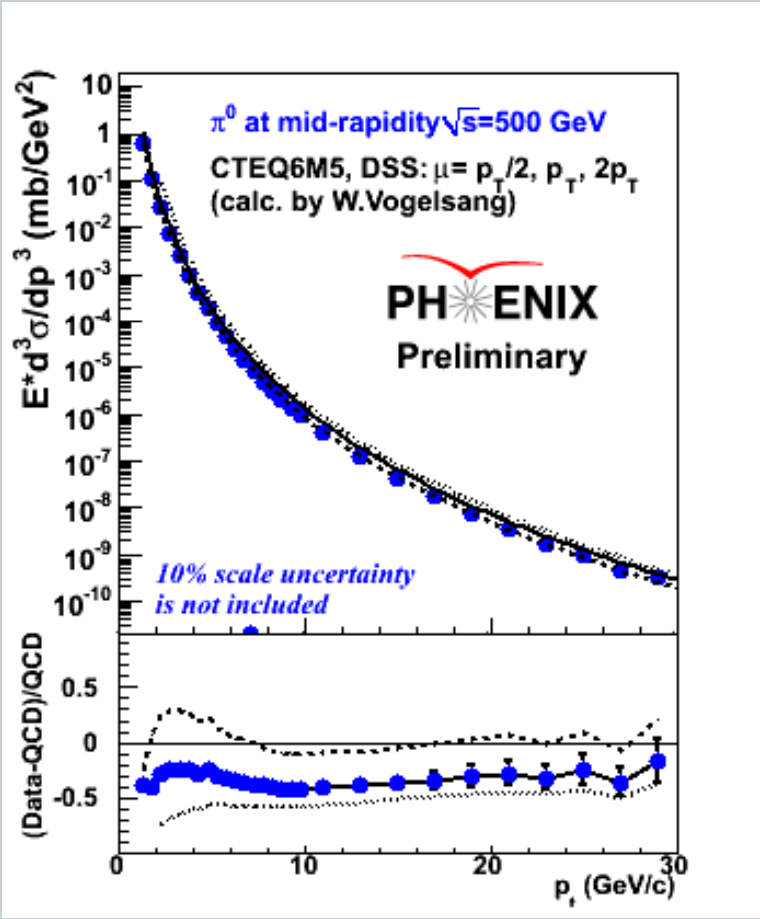


Cross section results from PHENIX (62 GeV and 500 GeV)

π^0 @ 62.4 GeV(PRD79, 012003)



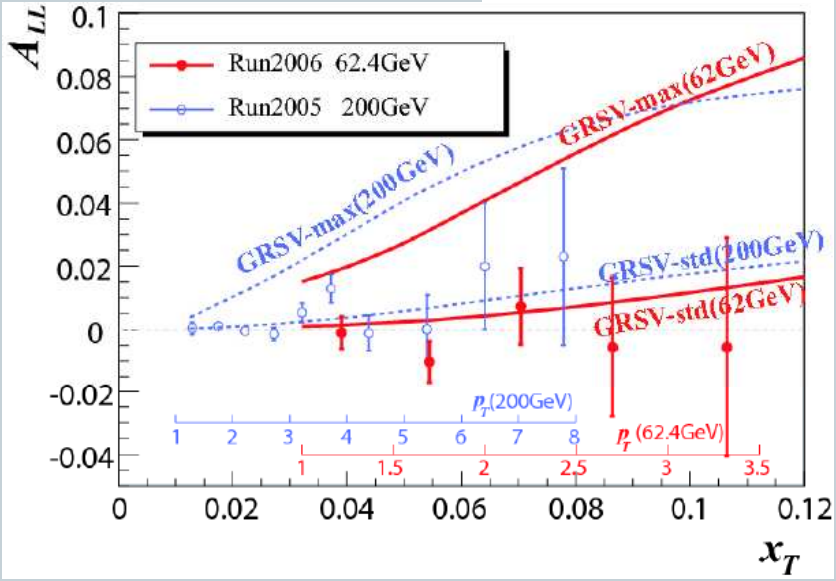
π^0 @ 500 GeV (2009)

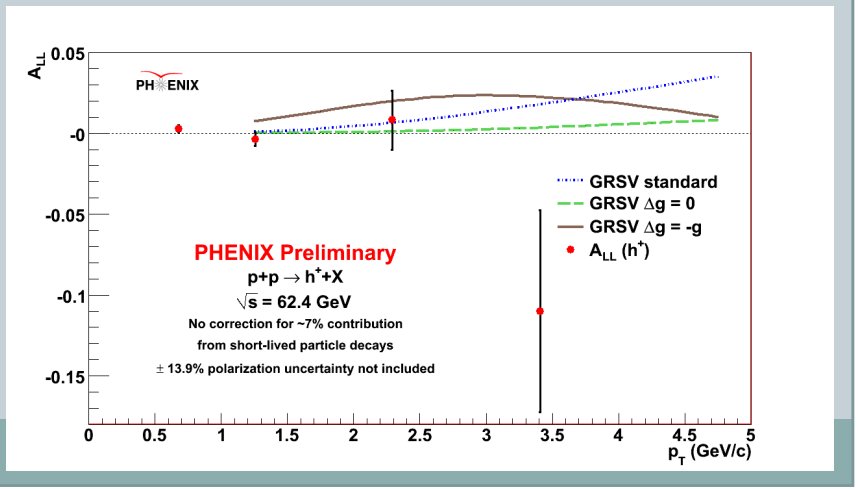


Extending x range at large x

PRD79, 012003

- π^0 A_{LL} at 62.4 GeV
  - clear statistical improvement at large
  - increased sensitivity to large x (0.06<x< 0.4)
  - overlap with 200 GeV A_{LL} providing measurements at same x_g but different p_T
  - a preliminary version of this data set already a part of a global analysis
  - Charge hadron at 62.4 GeV





A global analysis approach (DSSV)

Input world data

- Data selection:

"classic" inclusive DIS data

routinely used in PDF fits

! $\Delta q + \Delta \bar{q}$

semi-inclusive DIS data

so far only used in DNS fit

! flavor separation

first RHIC pp data (never used before)

! Δg

experiment	data type	data point fitted
EMC, SMC	DIS	34
COMPASS	DIS	15
E142, E143, E154, E155	DIS	123
HERMES	DIS	39
HALL-A	DIS	3
CLAS	DIS	20
SMC	SIDIS, $h^{\pm}$	48
HERMES	SIDIS, $h^{\pm}$	54
	SIDIS, $\pi^{\pm}$	36
	SIDIS, $K^{\pm}$	27
COMPASS	SIDIS, $h^{\pm}$	24
PHENIX (in part prel.)	200 GeV pp, π^0	20
PHENIX (prel.)	62 GeV pp, π^0	5
STAR (in part prel.)	200 GeV pp, jet	19
TOTAL:		467

467 data pts in total (10% from RHIC)

Marco Stratmann, Spin'08

Global analysis setup

- Parameterization defined at $Q_0^2 = 1$ GeV² for sea quarks

$$x\Delta f_j(x, \underbrace{1\,\text{GeV}}_{\text{input scale}}) = N_j\, x^{\alpha_j}\,(1-x)^{\beta_j}\,\overbrace{\left[1 + \kappa_j\sqrt{x} + \gamma_j x\right]}^{\text{possible nodes}}$$

and delta g , simple forms $k_j = 0$.

- Positivity a basic assumption,

$$|\Delta\sigma| \leq \sigma \qquad |\Delta f| \leq f$$

- assumptions on parameters unless data cannot discriminate,

impose: $\alpha_{\bar{u}} = \alpha_{u+\bar{u}} \qquad \alpha_{\bar{d}} = \alpha_{\bar{s}} = \alpha_{d+\bar{d}}$

$$\Delta s = \Delta\bar{s}$$

Do a fit !!

From A_{LL} to constraining ΔG

- Calculate π^0 A_{LL} based on best fit Pdfs from DSSV.
- Formulate a χ^2 using the world experimental data and uncertainties.
- Do a global analysis with this χ^2 and get the best fit for ΔG.
- Use Lagrange Multiplier to find a $\Delta\chi^2 = 1$ uncertainty.

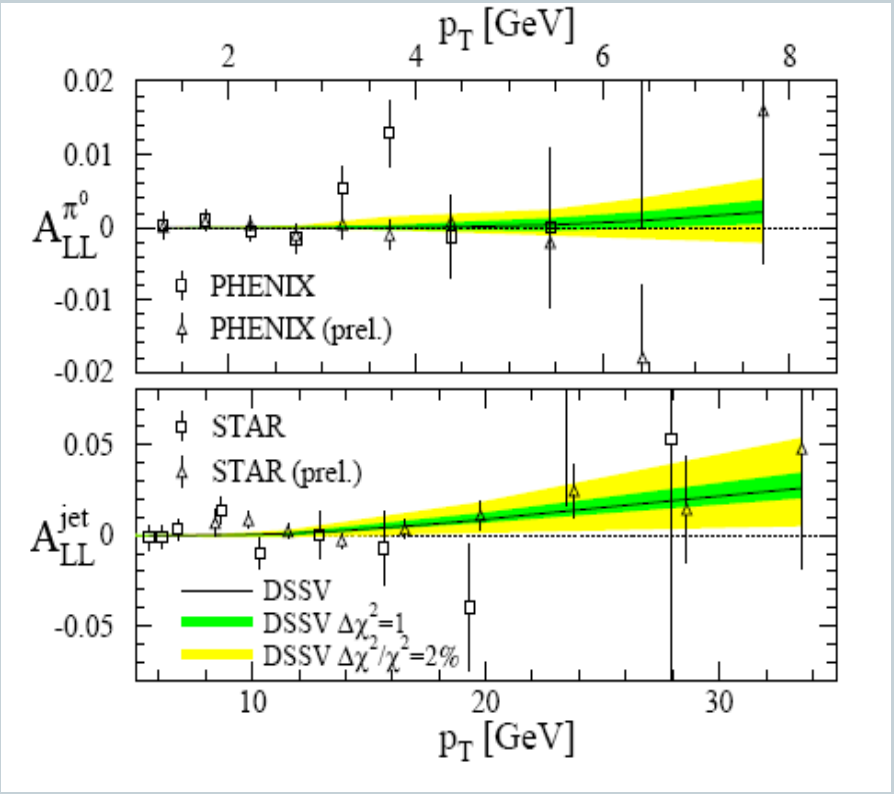
$$\chi'^2 = \chi^2 + \lambda\ \Delta f^{[a,b]}$$

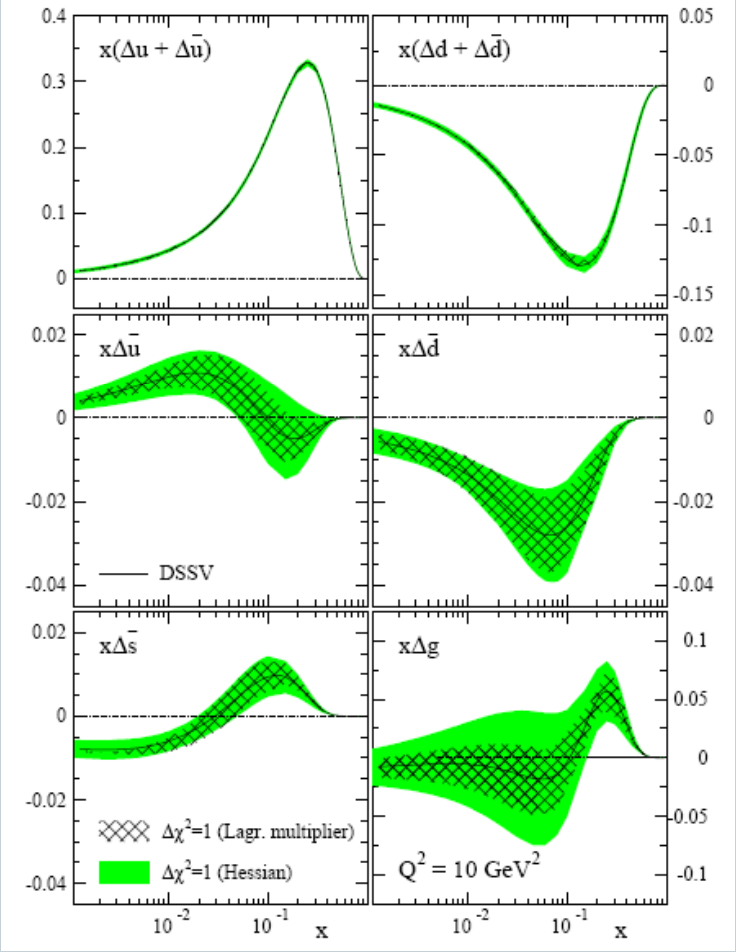
$$\Delta f = \Delta\Sigma, \Delta G$$

$$\Delta f^{[a,b]} \equiv \int_a^b dx \Delta f(x, \mu^2)$$

PDFs results and uncertainties from global analysis

Phys.Rev.Lett.101:072001,2008.





Constraining ΔG – a caveat

- Ignores correlation between x regions.

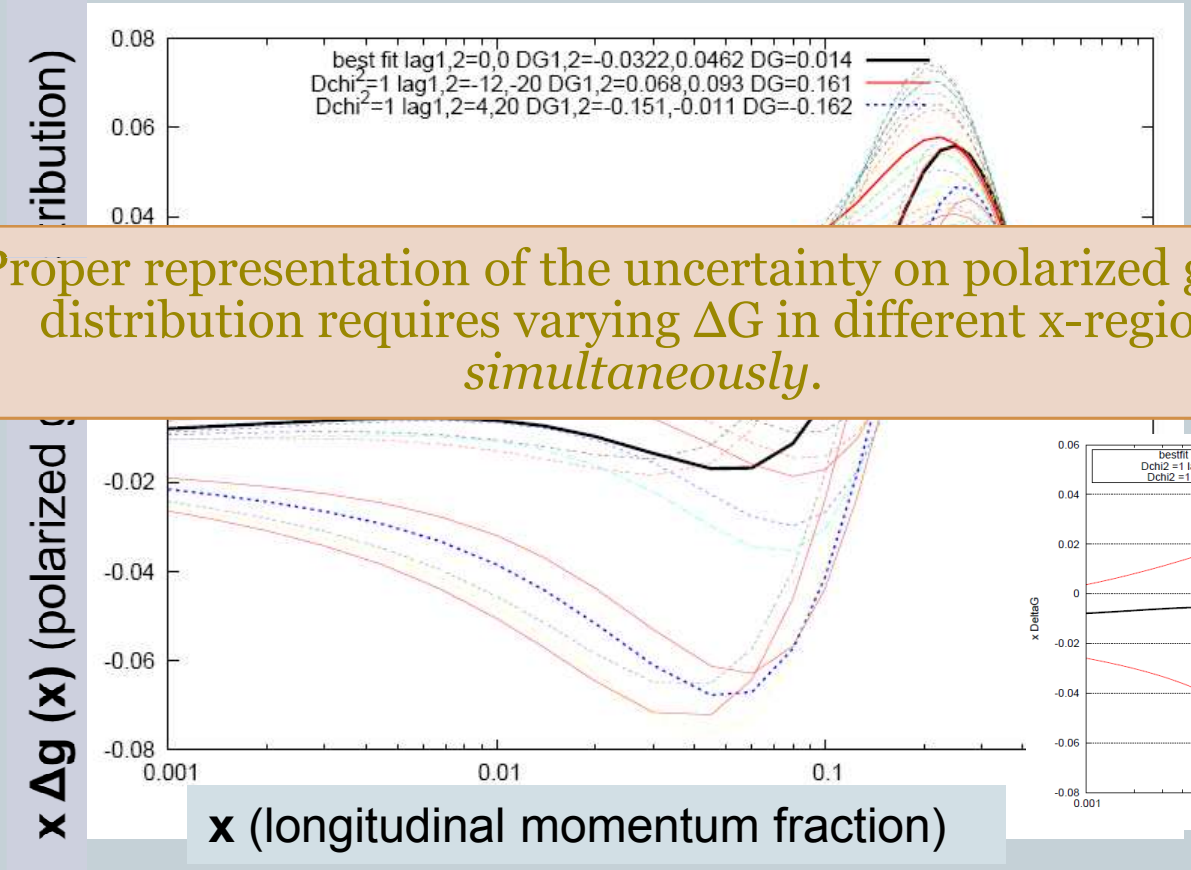
$$\chi'^2 = \chi^2 + \lambda\ \Delta f^{[a,b]}$$

- Splitting the x region, meaningfully, and constraining these regions simultaneously

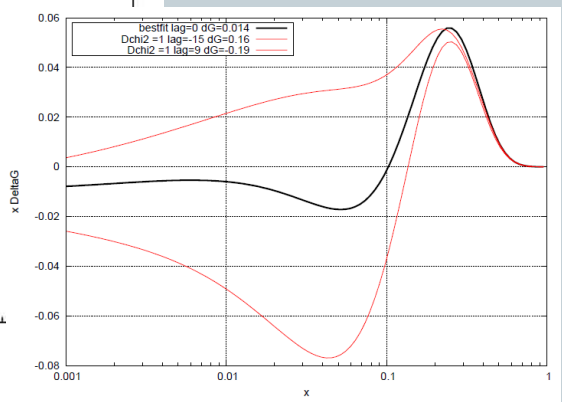
$$\chi'^2 = \chi^2 + \lambda_1 \Delta f^{[a,b_1]} + \lambda_2 \Delta f^{[b_1,b]}$$

Constraining ΔG – a caveat

- Uncertainty on pol. gluon due to two x ranges:



Proper representation of the uncertainty on polarized gluon distribution requires varying ΔG in different x-regions *simultaneously*.



Summary and Outlook

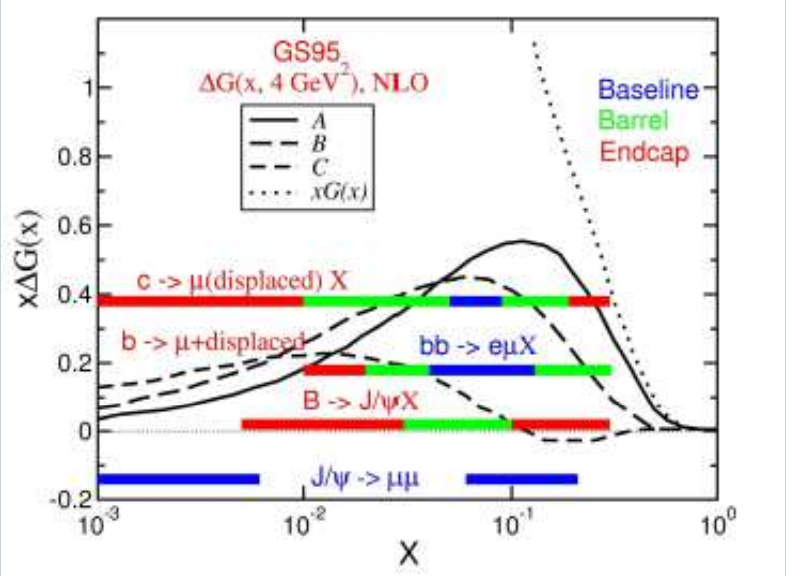
- PHENIX π^0 data offers strong constraint on ΔG as found by DSSV.
- 200 GeV data from Run9 and future runs will further significantly constrain ΔG.
- Other probes ($\pi^{+/-}$, γ, η) also can constrain ΔG, and will be used in future global fits.
- ΔG at lower x range ($x<0.02$) is presently being explored with $\sqrt{s}$ = 500 GeV at RHIC (2009 polarized pp run).
  - Future measurement at 500 GeV will help constrain ΔG given > 50%

- It is much too early to claim that $\Delta G=0$, as uncertainty in range $0<x<1$ is large

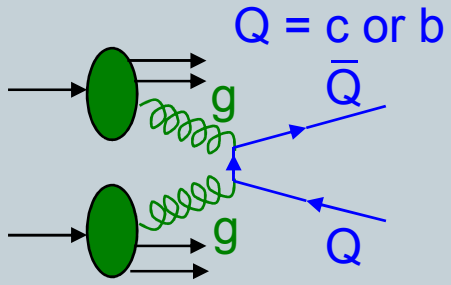
Back up

Vertex detector

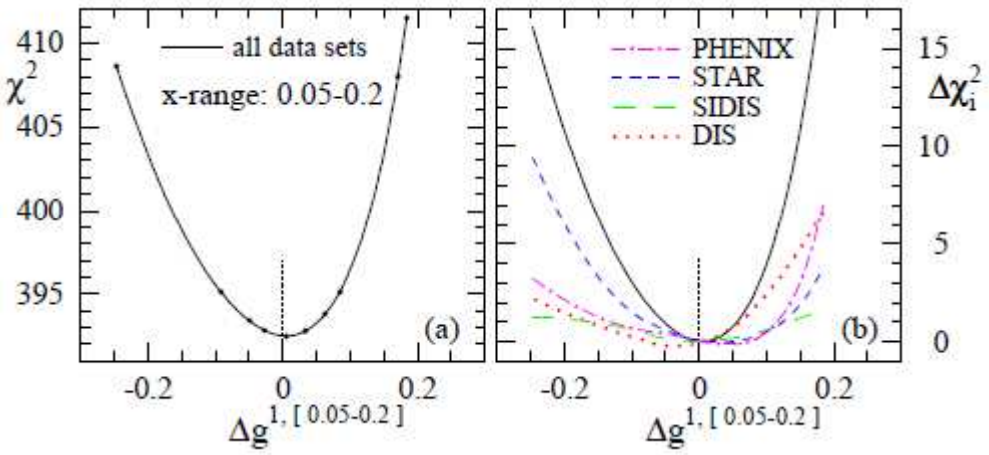
- The baseline PHENIX detector covers 0.02<x<0.3
- The vertex detector extends the reach in x for many of the measurements and hence adds a significant amount of overlap in x-range coverage.

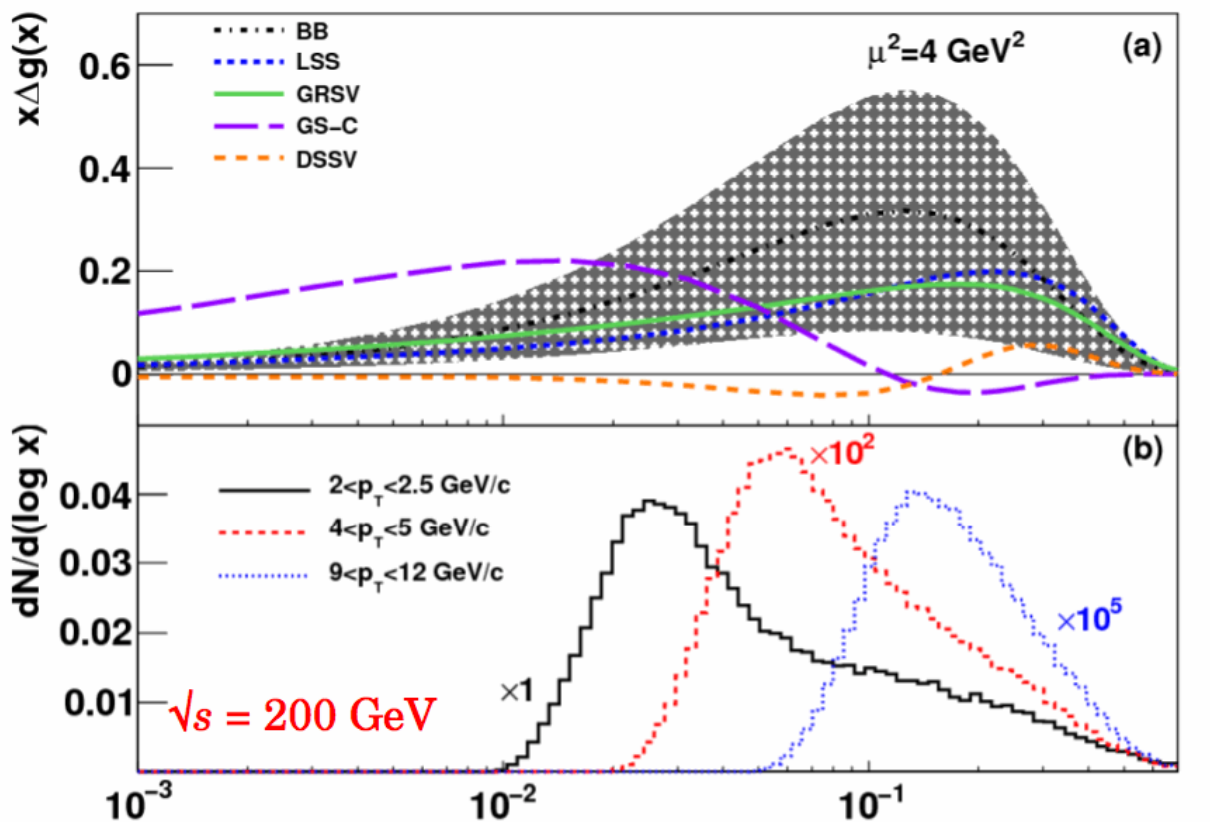


- Gluon spin (ΔG) with heavy flavor A_{LL}
- Improved x determination in γ-jet A_{LL} for ΔG



Impact on DeltaG





- NLO pQCD calculation of x distribution for 3 π^0 p_T bins.